Iot-Based Voltage And Current Monitoring For Industrial Load

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***Abstract*—The rapid integration of Internet of Things (IoT) technology with electrical monitoring systems has transformed conventional energy measurement and management practices. This work presents a compact, cost-effective, and real-time voltage and current monitoring system suitable for domestic, academic, and industrial applications. The proposed design is built around the PIC18F4520 microcontroller, which accurately acquires analog signals from a voltage divider network and an ACS712 Hall-effect current sensor. The processed data are displayed locally on a 16×2 LCD, allowing users to observe instantaneous voltage and current values on-site.**

For remote monitoring, the system employs both ESP8266EX Wi-Fi and GSM communication modules, enabling data transmission to the Thing Speak IoT cloud platform as well as through SMS alerts for redundancy and extended accessibility. A static IP configuration ensures stable and reliable cloud connectivity, while the GSM module provides continuous monitoring capability even in the absence of Wi-Fi. The Thing Speak dashboard offers an intuitive graphical interface to visualize voltage, current, and computed power variations over time. This dual-communication design empowers users to remotely monitor energy usage, identify abnormalities, and implement timely corrective actions, thereby improving efficiency, safety, and reliability in electrical systems.

Index Terms*—Internet of Things (IoT), Smart Energy Monitoring System, Voltage and Current Measurement, ACS712 Current Sensor, PIC18F4520 Microcontroller, ESP8266 Wi-Fi Module, GSM Communication, Thing Speak Cloud Platform, Real-Time Data Acquisition, Embedded System Design, Energy Management, Power Efficiency

I. INTRODUCTION

As global energy consumption continues to rise across residential, commercial, and industrial sectors, the demand for continuous, real-time monitoring of electrical parameters has become increasingly critical. The growing integration of renewable energy sources and smart grid technologies has placed additional stress on conventional power infrastructures. Traditional analog and standalone digital meters, though effective for basic measurements, lack essential modern features such as remote accessibility, automated control, predictive analytics, and data-driven decision-making capabilities required in today's intelligent power systems [1]–[3].

Recent advancements in the Internet of Things (IoT), embedded systems, and wireless communication technologies have revolutionized the monitoring and management of electrical networks. IoT-enabled energy systems facilitate real-time data acquisition, cloud-based storage, remote visualization, and predictive maintenance, significantly improving system reliability, operational efficiency, and safety [4]–[7]. These platforms provide continuous insight into key parameters such as voltage, current, power factor, and load behavior—enabling early fault detection, reduction of energy losses, and optimization of power utilization [8]–[10].

Furthermore, the combination of IoT with cloud computing enables large-scale data analytics, historical trend analysis, and automated alert mechanisms. Such systems empower both consumers and utilities to identify anomalies before they escalate into equipment failures or outages, thereby enhancing the overall resilience of the power grid [11]–[14]. Industrial substations and distribution transformers have already adopted IoT-based solutions for advanced diagnostics, predictive fault detection, and load analysis, resulting in reduced downtime, lower maintenance costs, and improved power quality [1], [14], [15].

Emerging studies have also shown that integrating Artificial Intelligence (AI) and Machine Learning (ML) algorithms into IoT-based monitoring systems enhances fault classification accuracy and enables adaptive, self-learning energy management [16]. However, most of these implementations are tailored for high-budget industrial infrastructures, making them less suitable for smaller, cost-sensitive applications such as homes, educational institutions, and laboratories.

To address this gap, the present work proposes a compact and scalable IoT-based voltage and current monitoring system tailored for low-cost, real-time energy management. The system utilizes the PIC18F4520 microcontroller for signal acquisition and processing [19], the ACS712 Hall-effect sensor for precise and isolated current measurement [17], and the ESP8266EX Wi-Fi module for wireless data communication [18]. Measured data are transmitted to the Thing Speak IoT cloud platform [20], where users can visualize real-time voltage and current trends, analyze power usage patterns, and detect potential anomalies. This design effectively bridges the gap between complex industrial-grade monitoring solutions and accessible, modular IoT-based systems for small-scale applications.

II. SYSTEM IMPLEMENTATION

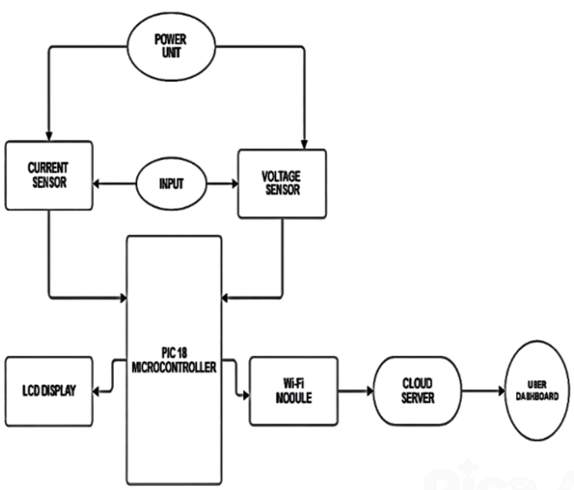

Figure 1: Block Diagram of IoT-Based Voltage and Current Monitoring System

The proposed IoT- and GSM-enabled Voltage and Current Monitoring System is developed as a compact, modular, and intelligent framework that integrates sensing, processing, communication, cloud analytics, and user interface functionalities into a unified embedded environment. The design emphasizes accuracy, scalability, energy efficiency, and real-time accessibility, ensuring suitability for domestic, academic, and industrial applications [1], [4], [5].

A. Hardware Implementation

The overall system is functionally organized into five major units — Sensing, Processing and Control, Communication and Output, Cloud and User Interface, and Power Supply. A high-level representation of the complete system architecture is illustrated in Figure 1.

The sensing unit continuously measures voltage and current from the connected load. The AC mains voltage is first stepped down through a transformer and further scaled using a voltage divider circuit to bring the level within the microcontroller's safe ADC input range. This ensures accurate measurement without damaging low-voltage components. The ACS712 Hall-effect current sensor [8], [9], [17] is employed for current measurement due to its galvanic isolation, high linearity, and low noise. Its analog output is directly proportional to the load current and is fed to the microcontroller's ADC input for digital conversion and computation.

At the heart of the system lies the PIC18F4520 microcontroller [19], which performs the essential processing and control functions. It converts analog signals into digital form using its in-built 10-bit ADC and computes real-time values of voltage, current, and power. The microcontroller also implements threshold-based decision logic to identify abnormal conditions such as overcurrent or undervoltage. In addition, it coordinates the data flow among various peripherals, including the LCD display, Wi-Fi module, and GSM unit, through its UART interface. The PIC18F4520 is chosen for its high reliability, low cost, and efficient performance in embedded energy-monitoring applications [6], [10].

The communication and output subsystem are responsible for both local and remote data visibility. For local display, a 16×2 LCD module presents instantaneous voltage and current readings, allowing users to monitor system parameters directly at the site. For wireless communication, the ESP8266EX Wi-Fi module [18] is integrated to transmit processed data to the Thing Speak IoT cloud platform [11], [12], [20] using standard TCP/IP protocols. This module ensures efficient data transfer over existing Wi-Fi infrastructure with low latency and wide coverage. To enhance system reliability and ensure continued operation in case of internet unavailability, a GSM-based alert system is also implemented using the SIM800L module. When abnormal events occur, such as excessive current or voltage fluctuations, the GSM module automatically sends SMS notifications to the registered user, ensuring uninterrupted awareness and safety [14], [15].

The cloud and user interface layer are implemented through the Thing Speak IoT platform, which provides real-time data visualization, long-term data storage, and analytical capabilities [11], [13]. Users can monitor live trends of voltage, current, and power through graphical dashboards accessible via any internet-enabled device. Things peak’s integrated MATLAB analytics feature also allows users to set automated alerts and perform predictive analysis to detect irregularities or potential faults before they escalate [16]. This cloud integration transforms the system from a traditional measurement setup into an intelligent, IoT-driven energy management solution.

The power supply unit provides stable and isolated DC voltages required by all components. A 5 V regulated DC source powers the microcontroller, sensors, and display, while a 3.3 V regulator supplies the ESP8266 Wi-Fi module. Safety elements, including fuses, metal oxide varistors (MOVs), and Zener diodes, protect the circuit from overvoltage, short circuits, and transient surges, ensuring reliability and system durability in fluctuating power conditions [18], [19].

B. System Operation

In operation, the sensing unit continuously measures the voltage and current, which are digitized and processed by the PIC18F4520 microcontroller. The computed power parameters are displayed locally on the LCD for on-site observation. Simultaneously, the processed data is transmitted via the ESP8266 Wi-Fi module to the ThingSpeak cloud, where users can visualize and analyze it in real time. In parallel, the GSM module ensures redundancy by sending SMS alerts whenever the system detects abnormal conditions or communication failures. This dual-mode data communication framework—combining IoT cloud and GSM-based alerting—enables continuous, reliable, and intelligent monitoring of electrical parameters, significantly improving safety, efficiency, and energy management in modern electrical systems.

III. RESULTS AND DISCUSSION

The implemented IoT- and GSM-based voltage and current monitoring system was experimentally tested under controlled laboratory conditions to validate its performance, accuracy, and reliability. The test setup consisted of three incandescent lamp loads (Load 1, Load 2, and Load 3), each connected across a common 230 V AC supply. Measurements were recorded for steady-state operating conditions, and data were transmitted both via Wi-Fi (to the Thing Speak IoT platform) and GSM (for SMS alerts).

A. Experimental Setup

The experimental setup consisted of a PIC18F4520 microcontroller interfaced with voltage and current sensors, a 16×2 LCD module for local display, and ESP8266 Wi-Fi and GSM modules for remote data transmission. The loads were powered from a common 230 V AC supply. The microcontroller continuously sampled analog signals, computed RMS values, and calculated real power using:

$P=V\times I$

Communication between modules followed the path MCU → Wi-Fi → GSM → Cloud Dashboard, ensuring reliable bidirectional data transfer. The complete experimental hardware assembly is shown in Figure 5, illustrating the interconnection between sensors, the controller, and communication peripherals.

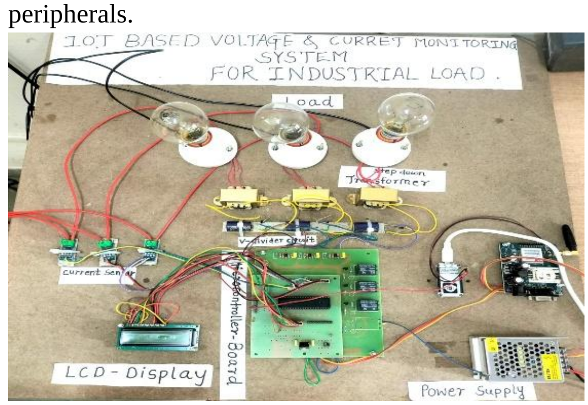

Figure 2. Hardware system setup

B. Measurement Results

The system was tested using three loads under steady-state conditions. Table 1 summarizes the averaged one-minute readings for each load. The measured RMS voltage remained constant across all loads, confirming supply stability. Corresponding current readings increased with load power rating, as expected for resistive elements.

Table 1. Measured voltage, current, and power for each load

Parameter	Load 1	Load 2	Load 3	Notes
Measured RMS Voltage (V)	229.6	229.6	229.6	Same mains for all loads
Measured RMS Current (A)	0.21	0.45	0.62	Sensor + ADC averages
Calculated Real Power (W)	48.22	103.32	142.35	P=V×IP = V \times IP=V×I

The 16×2 LCD module displayed real-time voltage and current readings, enabling on-site monitoring as depicted in Figure 4. This immediate display feature enhances system usability in domestic and industrial environments.

Figure 3: Hardware system working

C. Accuracy Evaluation

To validate accuracy, the results were compared with readings from a calibrated digital multimeter. Table 2 presents the reference and IoT-measured values along with their respective percentage errors.

Table 2. Accuracy comparison between reference and IoT-measured values

Parameter	Reference	IoT Measured	Absolute Difference	% Error
Voltage (RMS)	230.00 V	229.60 V	−0.40 V	−0.17 %
Current Load 1	0.200 A	0.210 A	+0.010 A	+5.00 %
Current Load 2	0.460 A	0.450 A	−0.010 A	−2.17 %
Current Load 3	0.600 A	0.620 A	+0.020 A	+3.33 %

The system achieved an average voltage error below 0.2% and a current error range of 2–5%, which is acceptable for real-time embedded monitoring systems using Hall-effect sensors and 10-bit ADCs. The small deviations were attributed to sensor tolerance, temperature drift, and analog-to-digital conversion rounding.

D. Real-Time IoT Dashboard Monitoring

The ESP8266 Wi-Fi module successfully transmitted measured data to the ThingSpeak IoT cloud platform. As illustrated in Figure 5, the dashboard provided a live graphical interface for voltage, current, and power trends. The plots confirmed continuous data streaming with updates every 3 seconds, minimal latency, and negligible packet loss.

Voltage trends displayed stable readings across all phases, while the current plots correlated directly with the connected load levels. A transient voltage dip on Phase 2 was effectively detected and visualized, validating the system's sensitivity and accuracy in detecting supply variations.

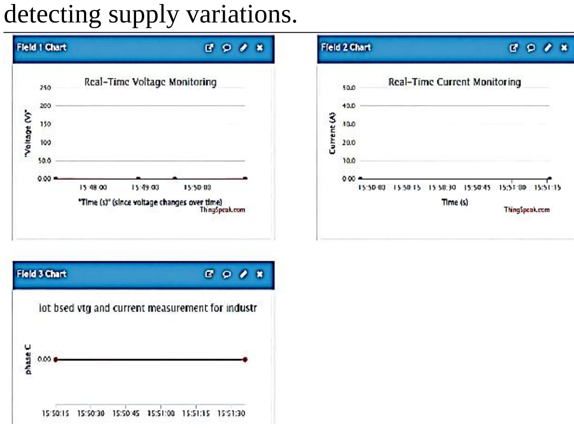

Figure 4: Thing Speak Dashboard

E. GSM-Based Alert Notification

In addition to IoT-based monitoring, the system integrated GSM communication for fault alerting and backup connectivity. When abnormal operating conditions such as under-voltage or over-current were detected, the GSM module automatically sent an SMS alert to the registered mobile user.

A sample notification, "Phase2 low voltage detected", was received during testing, as shown in Figure 6. The alert system responded promptly within seconds of event detection, confirming the reliability of the GSM-based communication link for real-time field alerts.

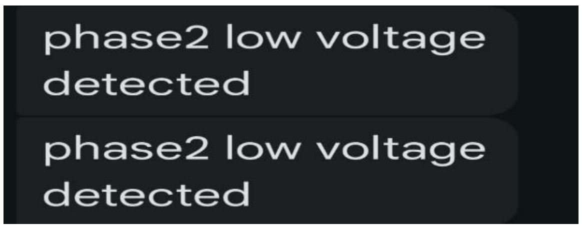

Figure 5: GSM Notification

F. Performance Discussion

The test results confirm that the proposed IoT- and GSM-enabled monitoring system effectively provides accurate, real-time, and redundant communication-based supervision of electrical parameters. The integration of cloud visualization (ThingSpeak) with SMS alerts enhances user awareness, operational reliability, and system responsiveness.

Overall, the measured accuracy, stable connectivity, and robust alert mechanism demonstrate that the design is well-suited for domestic, institutional, and industrial power management applications. The system's modular structure also allows easy scalability to include energy billing, load control, or power factor correction functionalities in future enhancements.

IV. CONCLUSION AND FUTURE WORK

A. Conclusion

The proposed IoT- and GSM-based voltage and current monitoring system has been successfully designed, implemented, and validated as a compact, low-cost, and scalable solution for real-time energy monitoring. The system integrates multiple subsystems—namely, the PIC18F4520 microcontroller, ACS712 Hall-effect current sensor, voltage divider network, ESP8266 Wi-Fi module, and GSM communication unit—to achieve accurate data acquisition, local display, cloud visualization, and mobile alert notification. Experimental results confirmed that the system consistently provided reliable voltage and current measurements with minimal error margins (below 5%) and ensured uninterrupted data transmission to the ThingSpeak cloud platform for real-time analysis.

The developed architecture effectively bridges the gap between traditional wired metering systems and modern IoT-enabled smart grids. By incorporating wireless communication and cloud-based analytics, users gain remote access to live electrical parameters, historical data logs, and automated notifications of abnormal operating conditions. The inclusion of an LCD interface for on-site monitoring further improves system usability, while power isolation and voltage regulation enhance safety and long-term stability. Moreover, the modular design allows easy customization for various load capacities, making the prototype equally suited for residential, laboratory, and small industrial applications.

From an energy management perspective, this system not only provides accurate measurement and visualization but also empowers users to identify inefficiencies, predict faults, and optimize power consumption patterns. The successful integration of IoT (ThingSpeak) with GSM alerting demonstrates dual communication reliability — cloud-based for data analytics and cellular-based for real-time emergency alerts, ensuring high system dependability even under network fluctuations.

B. Future Scope

To further enhance the accuracy, intelligence, and industrial adaptability of the developed three-phase IoT-based voltage and current monitoring system, several future improvements and research directions can be explored:

1. Advanced Power Quality and Phase Analysis

Although the current system successfully measures three-phase parameters, future enhancements can include power factor correction, phase imbalance detection, and total harmonic distortion (THD) analysis. Implementing FFT-based algorithms can help identify waveform distortions and harmonics, allowing the system to serve as a complete power quality analyzer for industrial and commercial setups.

2. AI-Based Fault Detection and Predictive Maintenance

By integrating machine learning (ML) models or artificial intelligence (AI) algorithms, the system can intelligently detect abnormal conditions such as voltage dips, current surges, unbalanced loads, or phase failures. Predictive algorithms can forecast potential equipment failures, enabling preventive maintenance and improving operational reliability in industrial environments.

3. Automated Load Management and Demand Control

The system can be upgraded to include automated load control using solid-state relays (SSRs) or IoT-based contactors, allowing remote switching, load shedding, or priority scheduling based on real-time demand and energy tariffs. This would convert the system from a monitoring tool into a smart energy management platform capable of optimizing power consumption.

4. Mobile Application and Voice-Enabled Access

Developing a dedicated Android/iOS mobile application would make monitoring more user-friendly through real-time dashboards, analytics, and notifications. Integration with voice assistants like Alexa, Google Assistant, or Siri can provide quick status queries and control commands through simple speech interaction, enhancing convenience in homes and industries.

5. Secure Cloud Connectivity and Edge Intelligence

Future versions can incorporate encrypted MQTT/HTTPS communication to ensure data privacy and network security. Additionally, edge computing can be used to perform initial data processing and decision-making locally before uploading summaries to the cloud, reducing bandwidth usage and improving response times for critical alerts.

6. Big Data Analytics and Cloud-Based Insights

Long-term data collected from multiple installations can be analyzed using big data tools or AI-based analytics platforms such as ThingSpeak MATLAB, AWS IoT Core, or Google Cloud IoT. This can support load forecasting, energy theft detection, and trend-based consumption analysis, helping industries and utilities improve decision-making and reduce wastage.

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